Flyback Design for Continuous Mode of Operation

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From our discussion in last month's Power Design column, we know that low cost and simplicity are the major advantages of the flyback topology. In multiple output applications, the addition of a secondary winding, a diode, and an output capacitor is all that's required for an additional output. If one output is closed loop voltage stabilized, then all other outputs are semi-stabilized to limits acceptable in many applications.

The "continuous conduction mode flyback transformer" presents us with a more difficult design challenge. This stems from the fact that flyback transformers are not really transformers. In fact, in the continuous flyback mode, the transformer is more correctly a choke carrying ac and dc currents. The term transformer is used because the choke has additional windings referred to as secondaries. However, unlike a true transformer, the secondary voltages are not necessarily related to the primary/secondary turn's ratio. Let's look at the design of a continuous mode flyback "transformer" and present one more example of the function of an air gap in a ferrite core.

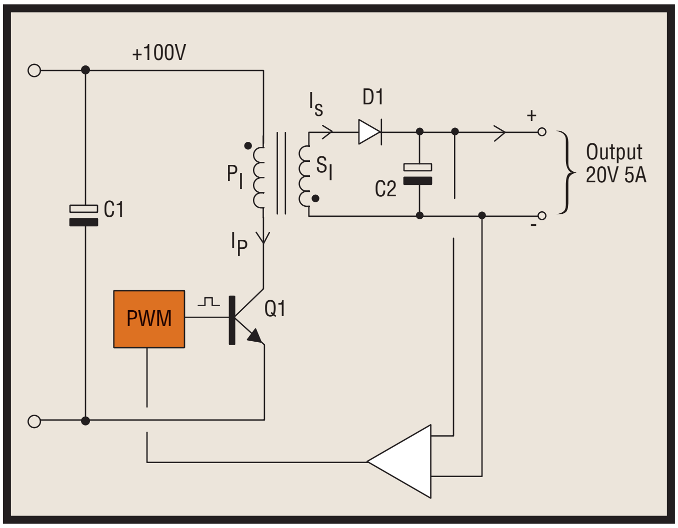

Fig. 1. *Basic topology of a typical dual output flyback converter.*

Functional Principles

Fig. 1 shows the basic topology of a typical dual output Flyback Converter. In the continuous mode, energy is stored in the magnetic field of the core and air gap during the ON period of Q1. However, unlike the discontinuous mode, not all of the stored energy is transferred to the secondary when Q1 turns OFF (hence, the term *incomplete energy transfer mode*). However, do not allow this term to mislead you; the actual power throughput is normally greater in the incomplete transfer mode. You can see this from the waveforms shown in **Fig. 2**, on page 60. Clearly, the area under the current waveform for the continuous mode **Fig. 2(a)** is larger than the discontinuous mode **Fig. 2(b)**, providing the peak current remains the same. Notice that the current waveform in **Fig. 2(a)** shows a variable (sloping) top part, sitting on top of a rectangular dc current component, this waveform is similar to the waveform seen in a typical output smoothing choke.

The dc current component is transferred from the input to the output—in addition to a proportion of the energy stored in the core—by the gating action of Q1 and the output diodes. Thus, both the dc part and the ac part contribute to the total power throughput.

Consequently, in the continuous mode flyback transformer, an inductor action becomes integrated into the "transformer" which must now provide both transformer isolation and choke action in a single wound component, making the design a little more difficult.

Referring again to **Fig. 1**, we can examine the flyback action a little closer. When Q1 turns ON the primary voltage (the prime force) is applied to the primary winding, the start of the winding goes positive, and current builds up in the winding flowing from the start (the dot) to the finish. The magnetic field grows from the winding into the core cutting its own windings in the process, and generating an internal "back emf" opposing the applied voltage. When Q1 turns OFF (removing the applied voltage), the internal back emf now becomes the new prime force. However, the previously established magnetic field is now shrinking back into the winding from the core, cutting the windings in the reverse direction; hence the "back emf" changes direction, taking the start of all windings negative. This is the origin of the "flyback voltage." The magnitude and polarity of the flyback voltage is a function of the rate of change of magnetic field and the direction of the change.

However, the magnitude and direction of the current is proportional to the magnitude and direction of the magnetic field in the core. At the instant of turn OFF of Q1, this has not changed. The current continues to flow from start to finish in any winding it can find that will conduct.

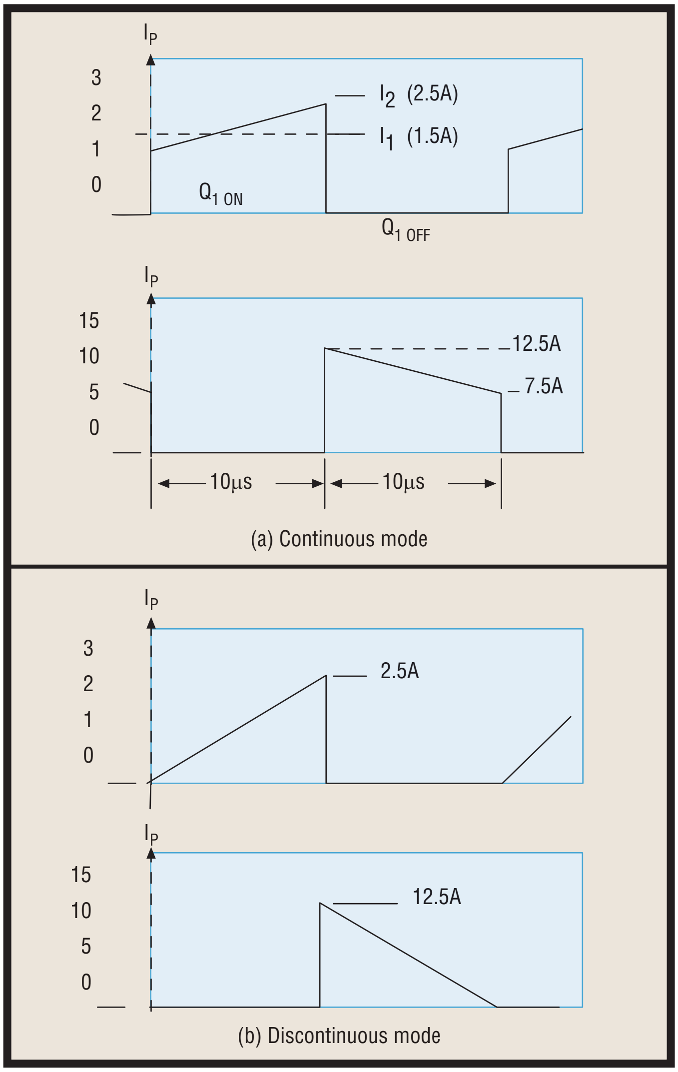

Fig. 2. *Current waveforms for* **(a)** *Continuous mode and* **(b)** *Discontinuous mode.*

In this example, S1 provides a path, the *current* flowing from start to finish within the secondary and out through D1 into the output capacitor C2 and the load. (*More correctly, the ampere turns product will be maintained).*

Fig. 3, on page 62, shows an idealized B/H characteristic for the continuous mode flyback transformer. The lower diagram shows the current waveform with respect to time where "H" has been converted to its effective current. Characteristics are shown for two different core gaps, applied to the same transformer. Notice, the ac flux density swing ΔB remains the same for both gap sizes because the primary turns, primary voltage and frequency remain the same. However, the larger gap provides a larger current waveform with more output power and more ripple current. Thus, we see one more function for the air gap.

Notice, since the core loss is related to ΔB, the core loss remains constant for both gap sizes. However, since the mean current increases, the copper loss will also increase in the ratio $Irms^2$, so there is a thermal limit to how far you

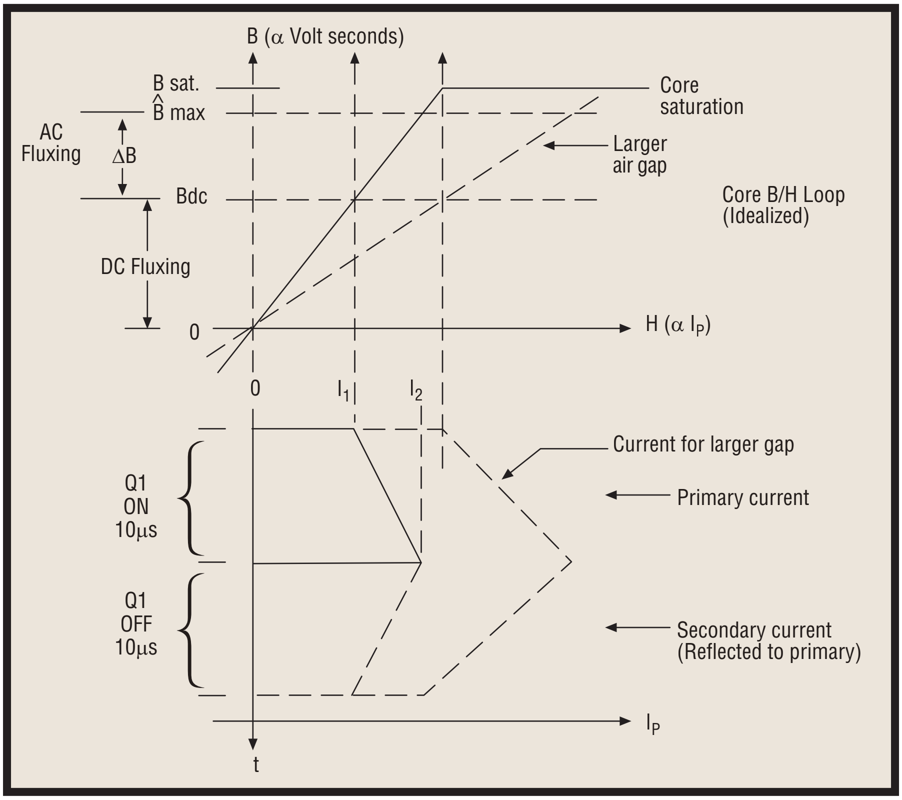

Fig. 3. *An idealized B/H characteristic for the continuous mode flyback transformer.*

increase the core gap and output current. Further, the design will not remain optimum, because the copper and core loss are no longer equal. Such designs are said to be copper loss limited. This inequality is permitted, providing it is the design intention and appropriate cooling is provided).

Look for Part 3 of this series in next month's issue, where we'll cover the actual transformer design for a 100W continuous mode flyback converter, as discussed above. **PETech**

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